

SYNERGY OF AATSR AND SCIAMACHY FOR CLOUD THERMODYNAMIC PHASE DETERMINATION

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ABSTRACT

A new technique to identify the thermodynamic phase of cloudy media using satellite measurements is proposed. The technique is based on measurements of the backscattered solar light at wavelengths 1.55 and 1.67 micrometers in combination with the cloud brightness temperature measurements at 12 micrometers.

The cloud top temperature and the cloud phase index are obtained using data from Advanced Along Track Scanning Radiometer (AATSR) and SCAning Imaging Absorption spectroMeter for Atmospheric Chartography (SCIAMACHY) both onboard the ENVIronemntal SATellite (ENVISAT).

It is shown that the correlation plot of the cloud top temperature against the cloud phase index defined as the ratio of the reflection function at 1.55 micrometers to that at 1.67 micrometers can be used to identify regions with water, ice, and mixed clouds.

1 INTRODUCTION

The thermodynamic state (TS) of clouds influences precipitation, atmospheric dynamics, radiation, heat and mass transfer. The proper partitioning of cloud phase is particularly important in precipitation processes as it directly impacts on the type of hydrometeors released (rain, snow, hail, sleet...). The identification of cloud thermodynamic phase is not only critical for precipitation prediction but also to specify the accurate optical and microphysical properties of clouds. In this respect, the determination of the phase of clouds should be regarded as the first step in algorithms designed for the retrieval of cloud properties from satellite measurements[1]. Additionally, the assessment of the TS of clouds is relevant to the solution of applied problems such as the icing occurring on an aircraft. As a result, the problem of the TS determination attracted a considerable amount of attention in the past[1-6]. In particular, a comprehensive dataset related to the cloud TS was obtained using satellite – based infrared observations in [3]. It was found that, generally, the brightness temperature difference between channels located at 8.5 and 11 micrometers is positive for ice clouds and this difference is negative for water clouds. However, one important shortcoming of an IR – based method to detect the cloud phase is due to the fact that the technique is not capable to deal with supercooled water or mixed-phase clouds.

We propose here to use in addition to thermal infrared data, measurements at wavelengths 1.55 and 1.67 micrometers. In fact, it is known that the absorption spectra of ice and water display significant differences in the spectral range 1.55-1.67 micrometers [1, 2]. Therefore, this specific behavior can be used to enhance the thermodynamic phase retrievals based on thermal infrared measurements. Unfortunately, instruments capable of measuring radiances simultaneously at wavelengths 1.55, 1.67, 8.7 and 11 micrometers are not available. Consequently, simultaneous satellite measurements over the same cloud field but using different instruments installed on the same space platform were combined to infer cloud field TS. This technique enables the discrimination of warm water clouds from ice clouds, mixed phase states, and supercooled water clouds.

Specifically, we used measurements at the wavelength 12 micrometers from the Advanced Along Track Scanning Radiometer on ENVIronemntal SATellite. Measurements at 1.55 and 1.67 micrometers were obtained using SCAning

Imaging Absorption spectroMeter for Atmospheric Chartography[7]. Further information on these instruments can be found at the following website: <http://www.esa.int/envisat/instruments.html>. In this study, SCIAMACHY measurements had a spatial resolution of $30 \times 60 \text{ km}^2$ whereas AATSR data had a resolution of 1 km^2 . Therefore, the AATSR measurements were integrated to the size of SCIAMACHY pixel. Additionally, only SCIAMACHY pixels with cloud fractions c above 99% and over an underlying ocean surface were used in this study. The values of c for SCIAMACHY pixels were obtained using collocated highly spatially resolved AATSR data. The AATSR pixel has been considered as a completely cloudy one if the reflection function R in the visible correspondent to this pixel exceeded the threshold value $R_c=0.2$.

2 RESULTS

A browse image of the scene analyzed from the orbit 08094 (17.09.2003, 14:50-15:03 UTC) of ENVISAT is shown in Fig. 1. It displays a portion of Hurricane Isabel close to the coast of Florida. The scatter diagram of phase index-temperature for the whole area is shown in Fig.2. Every point on this Figure corresponds to one $30 \times 60 \text{ km}^2$ SCIAMACHY pixel. Only cloudy pixels with cloud coverage above 99% were selected for this study. The phase index P is defined as the ratio of the reflection function at 1550nm to that at 1670nm. Generally, the atmospheric extinction decreases with the wavelength. This leads to smaller atmospheric optical thickness and also

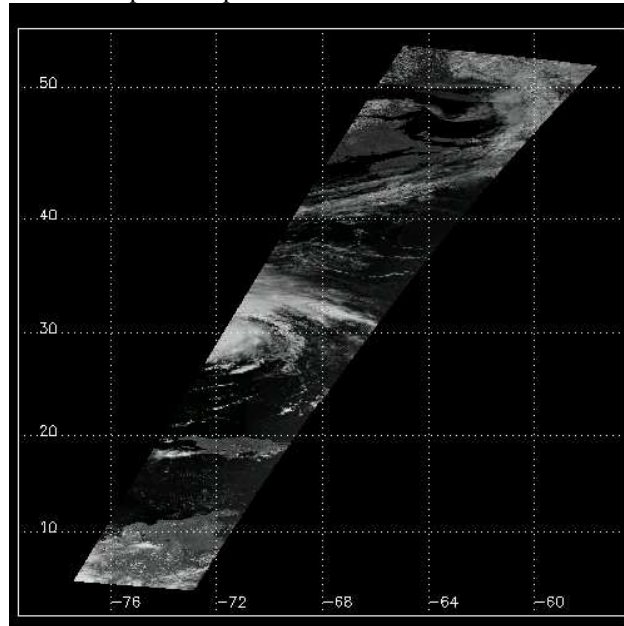


Fig. 1. Browse image of the scene studied. A sample of Hurricane Isabel (17.09.2003, 14:50UTC) captured by AATSR instrument on board ENVISAT (orbit 08094) is seen in the middle of image.

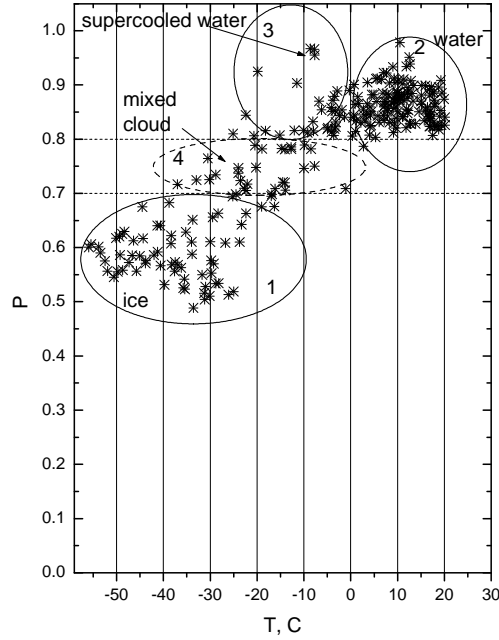


Fig. 2. P - T diagram. The temperature T is expressed in degrees Celsius (see the text) using brightness temperature measured by AATSR assuming that cloud can be represented as a black body. The phase index P is defined as the ratio of the reflectance at 1550nm to that at 1670nm. Each point in this figure corresponds to one completely cloudy SCIAMACHY pixel (see Fig.1).

smaller reflection function for larger wavelengths. Therefore, one may expect that P is larger than one for cloudless atmosphere over ocean. The value of P is smaller than one for clouds due to enhanced light absorption by liquid water or ice at 1670nm as compared to that at the wavelength 1550 nm. An interesting point is that the value of P is systematically smaller for ice as compared to liquid water.

We have performed radiative transfer calculations of P in the assumption that both cloud droplets and crystals have the spherical shape. The cloud optical thickness was varied in the range 5-30. The effective radii of droplets and crystals were changed in the range 5-30 micrometers. We found that P is in the range 0.5-0.7 for most of ice cloud cases. Interestingly, our calculations are confirmed by Fig.2 as well since it is known that water droplets do not exist at temperatures below -40°C .

The detection of clouds with supercooled water droplets is difficult with the concept of the phase index standing alone. On the other hand, mixed clouds can hardly be discriminated only using the temperature T . The cloud top temperature T in degrees Celsius as shown in Fig.2 is equal to $t - 273.15$, where t is obtained from the measured brightness temperature (at 12 micrometers) assuming that the cloud can be modeled as a black body. Therefore, our technique is not suitable for semi-transparent ice (cirrus) clouds where the surface temperature would affect the determination of T in the P - T diagram.

The P - T diagram shown in Fig.2 allows us to classify clouds with respect to their phase. It follows from Fig.2 that the phase index is always larger than 0.8 for warm water clouds ($T > 0$ degrees Celsius). It is in the range 0.5-0.7 for cold ice clouds ($T < -40$ degrees Celsius). Usually, clouds with negative temperatures ranging from zero to -40 degrees Celsius are difficult to classify. However, taking threshold values 0.7 and 0.8 established above, we can identify liquid and solid water as shown in Fig.2 even in this problematic region (the remaining data corresponding to mixed phase clouds). In particular, four separate areas present on the diagram shown in Fig.2 :

Region 1: predominantly ice crystals are present. We see that pure crystalline clouds do not exist at temperatures above -20°C for the case studied. Indeed, for $T > -20^{\circ}\text{C}$, the values of P become larger than 0.7 thus indicating the presence of liquid water droplets. Moreover, our particle size retrievals (not given here) show that crystals at lower temperatures have generally smaller sizes as compared to the case of ice clouds at higher temperatures.

Region 2: warm water clouds. It follows from Fig.2 that $P \geq 0.8$ for warm water clouds ($T > 0^{\circ}\text{C}$). Therefore, values of P larger or equal to 0.8 at negative temperatures T indicate supercooled water droplets.

Region 3: clouds with supercooled water droplets. There are a lot of clouds with supercooled droplets in the temperature interval $[-20^{\circ}\text{C}; 0^{\circ}\text{C}]$ for the case studied.

Region 4: mixed-phase clouds. This region is of a great importance for the formation of the precipitation. Interestingly, mixed clouds can exist in a wide range of temperatures down to -37°C .

A technique solely based on the thermal IR measurements will identify clouds at $T > 0^{\circ}\text{C}$ as liquid water clouds and clouds with temperatures below -40°C as crystalline ones. Therefore, it is difficult to assess the thermodynamic state in the region from -40°C till 0°C by the only use of thermal infrared measurements. However, we see that the concept of the phase index allows us to identify ice, supercooled water, warm water, and mixed clouds using the P - T diagram shown in Fig.2. The concept of the phase index alone is not capable to distinguish regions with warm clouds and supercooled droplets (see Fig.2). However, this is possible using the P - T diagram presented here for the first time.

3 CONCLUSIONS

We propose a technique to identify various phases of water in clouds using near IR and thermal IR measurements. On one hand, this shows the importance of synergy between various instruments on the same space platform (e.g., AATSR and SCIAMACHY on ENVISAT). On the other hand, this demonstrates the potential of adding one more channel (e.g., 1.55 micrometers) to the set of wavelengths available on AATSR (0.55, 0.67, 0.87, 1.6, 3.7, 10.7, and 12.0 micrometers) for the cloud research.

The advantage of the P - T diagram technique lies in the fact that it does not require complex numerical calculations. Also the method is very fast and simple. The technique can be used as the basis for the automatic cloud thermodynamic state determination numerical procedure using the analysis of the P - T thresholds as explained above. Clearly, independent measurements are needed to validate the performance of our technique. It is of advantage to develop an instrumentation, which is capable to measure radiation at wavelengths 1.55, 1.67, and 12 micrometers simultaneously and with a high spatial resolution.

The task of this paper was to demonstrate the capability of the technique with the current state-of-art instrumentation. The technique can be used as a way to get an additional cloud product from the synergy of AATSR and SCIAMACHY measurements.

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